SEMICONDUCTOR DEVICE AND METHOD FOR FABRICATING THE SAME

BACKGROUND OF THE INVENTION

The present invention generally relates to a semiconductor device having a copper wiring and a method for fabricating the same.

With increase in operation speed of transistors, the delay due to CR (capacitance-resistance) components of wirings has become a matter of concern in silicon LSIs (large scale integrated circuits) of 0.18 μm generation and the subsequent generations. Therefore, as a wiring material, Al (specific resistance of 3 μΩ · cm) is being increasingly replaced with Cu having a lower resistance (specific resistance of 1.7 μΩ · cm) or a metal primarily consisting of Cu (hereinafter, referred to as a "copper alloy"). Note that a wiring formed from copper or a copper alloy is herein referred to as a copper wiring.

Hereinafter, a conventional method for fabricating a semiconductor device will be described with reference to FIGS. **6A** through **6E**. Herein, the copper wiring fabricating technology using a Ta film (specific resistance of 200-230 μΩ · cm) as a barrier metal film is described by way of example.

First, as shown in FIG. **6A**, a first wiring **13** of a

copper film is embedded in a first insulating film **11** on a semiconductor substrate **10** with a first barrier metal film **12** of a Ta film interposed therebetween. Then, a first silicon nitride film **14**, a second insulating film **15**, a second silicon nitride film **16** and a third insulating film **17** are sequentially deposited on the semiconductor substrate **10**. A via hole **18** reaching the first wiring **13** is then formed through the first silicon nitride film **14**, second insulating film **15** and second silicon nitride film **16**. A wiring trench **19** reaching the first wiring **13** through the via hole **18** is also formed in the third insulating film **17**. The first barrier metal film **12** or the first silicon nitride film **14** prevents copper atoms of the first wiring **13** from diffusing into the first insulating film **11**, the second insulating film **15** or the like due to the thermal processing at about 400°C for depositing the second insulating film **15**, the second silicon nitride film **16** or the like. In other words, the first barrier metal film **12** or the first silicon nitride film **14** serves as a barrier against diffusion of the copper atoms.

Then, as shown in FIG. **6B**, a second barrier metal film **20** of a Ta film and a copper seed layer **21** of a copper film are sequentially deposited on the bottoms and wall surfaces of each of the via hole **18** and the wiring trench **19** by a sputtering process.

The semiconductor substrate **10** is then transferred from

the sputtering apparatus into a plating apparatus. At this time, the surface of the semiconductor substrate **10**, i.e., the surface of the copper seed layer **21**, is exposed to the air. Then, as shown in FIG. **6C**, a copper plating film **22** is grown on the copper seed layer **21** by an electroplating process so as to completely fill the via hole **18** and the wiring trench **19**.

Thereafter, the copper plating film **22** is thermally processed (e.g., at about 100℃ for about two hours) in order to grow crystal grains of the copper plating film **22**. Thus, as shown in FIG. **6D**, the copper seed layer **21** and the copper plating film **22** are integrated into a wiring copper film **23**.

As shown in FIG. **6E**, those parts of the second barrier metal film **20** and the wiring copper film **23** which are located outside the wiring trench **19** are then removed to form a via **24** and a second wiring **25** from the wiring copper film **23**. Thus, the first wiring **13** is connected to the second wiring **25** through the via **24**.

Although not shown in the figure, a desired multi-layer wiring structure is then formed as necessary by repeatedly conducting the steps of FIGS. **6A** through **6E** (regarding FIG. **6A**, the step of depositing the first silicon nitride film **14** and the subsequent steps).

In the conventional fabrication method of the semiconductor device, however, the copper seed layer **21**

deposited by the sputtering process may have a reduced thickness on the wall surface of the via hole **18** due to the directivity of the sputtering process, as shown in FIG. **7A**. Thus, those parts of the second barrier metal film **20** which are located on the wall surface of the via hole **18** may possibly be exposed. As described before, the surface of the semiconductor substrate **10** is exposed to the air during transfer thereof from the sputtering apparatus into the plating apparatus after deposition of the copper seed layer **21**. Thus, if the second barrier metal film **20**, i.e., the Ta film, has exposed parts, those parts will be exposed to the air and therefore oxidized. In this case, the resultant Ta oxide is a dielectric with very poor electric conductivity. Thus, when the copper plating film **22** is grown by electroplating to fill the via hole **18**, an electric current does not flow through those oxidized parts of the second barrier metal film **20**. This may result in filling defects such as voids in the via hole **18** or the like as shown in FIG. **7B**. Those filling defects are induced even when a TaN film (specific resistance of 200-230 $\mu\Omega \cdot$ cm), a Ti film (specific resistance of 50 $\mu\Omega \cdot$ cm) or a TiN film (specific resistance of 200 $\mu\Omega \cdot$ cm) is used as the second barrier metal film **20**.

In order to fill a recess formed in the insulating film on the substrate with a copper film, a process such as a combination of sputtering and reflow processes, or a CVD

(chemical vapor deposition) process may be used instead of the electroplating process.

Suppose that the combination of sputtering and reflow processes is used instead of the electroplating process and also that an oxidation-reduction reflow process (Proc. of the 42nd Annual Meeting of JSAP (Spring, 1995), p. 810, Cu Wiring Technology (1) - Reduced-Temperature Cu Reflow with Redox Cycle Reaction -)) is used as the reflow process in the combination of sputtering and reflow processes. In that case, a thick copper film is deposited by a sputtering process on the insulating film in which the recess is formed with a barrier metal film of, e.g., a Ta film interposed therebetween. The copper film is then repeatedly oxidized and reduced in an oxidative-reducing atmosphere by an oxidation-reduction reflow process. The resultant reaction heat causes the copper film to flow, thereby completely filling the recess. However, when the copper film is oxidized, the conductivity of the barrier metal film is substantially lost due to the oxidation thereof, i.e., the oxidation of the Ta film or the like. As a result, the resistance of the wiring, the via or the like as well as the barrier metal (which will be herein merely referred to as "wiring resistance") will increase. The increase in wiring resistance is induced even when a copper film formed on the insulating film (which may have a recess therein) by the

electroplating process, combination of sputtering and reflow processes, CVD process or the like is patterned into a wiring.

SUMMARY OF THE INVENTION

A first object of the present invention is to enable a conductive film to be formed on a seed layer or a barrier metal film in a recess by an electroplating process, while preventing generation of filling defects.

A second object of the present invention is to prevent an increase in wiring resistance due to oxidation of the barrier metal film.

In order to achieve the first and second objects, a first semiconductor device according to the present invention includes an insulating film formed on a substrate and an embedded wiring of copper or a copper alloy formed in the insulating film. In the device, a barrier metal film of a metal whose conductivity will not be lost when the metal is oxidized or of a conductive metal oxide is formed between the insulating film and the embedded wiring.

In the first semiconductor device, the barrier metal film of a metal whose conductivity will not be lost when the metal is oxidized or of a conductive metal oxide is formed between the insulating film and the embedded wiring. Thus, when a conductive film which will be the embedded wiring is formed by an electroplating process, the following effects

can be achieved. Suppose that the barrier metal film and a seed layer are sequentially deposited on wall surfaces of a recess (a wiring trench, a via hole or the like) formed in the insulating film. In that case, even when the barrier metal film has exposed parts due to poor coverage of the seed layer, it can be avoided that the conductivity of the exposed parts of the barrier metal film will be substantially lost due to the oxidation of its exposed part. This enables the formation of the conductive film on the seed layer or the barrier metal film located in the recess by the electroplating process, while preventing generation of filling defects. When the conductive film which will be the embedded wiring is formed by some process other than an electroplating process, the following effects can be achieved. That is to say, when the barrier metal film is deposited on wall surfaces of the recess and then the conductive film is formed on the barrier metal film, e.g., in an oxidative atmosphere, it can be avoided that the conductivity of the barrier metal film will be substantially lost due to the oxidation thereof. Thus, wiring resistance can be prevented from increasing due to the oxidation of the barrier metal film.

In order to achieve the second object, a second semiconductor device according to the present invention includes an insulating film formed on a substrate and a

wiring of copper or a copper alloy formed on the insulating film. In the device, a barrier metal film of a metal whose conductivity will not be lost when the metal is oxidized or of a conductive metal oxide is formed between the insulating film and the wiring.

According to the second semiconductor device, the barrier metal film of a metal whose conductivity will not be lost when the metal is oxidized or of a conductive metal oxide is formed between the insulating film and the wiring. Thus, when the barrier metal film is deposited on the insulating film and then the conductive film for the wiring is formed on the barrier metal film, e.g., in an oxidative atmosphere, it can be avoided that the conductivity of the barrier metal film will be substantially lost due to the oxidation thereof. Thus, wiring resistance can be prevented from increasing due to the oxidation of the barrier metal film.

In the first and/or second semiconductor devices, the metal is preferably Ru, Ir or an alloy containing Ru or Ir.

Then, the barrier metal film can be prevented from substantially losing its conductivity due to the oxidation thereof as intended.

In the first and/or second semiconductor devices, the metal oxide is preferably RuO_2, IrO_2 or an alloy oxide containing Ru or Ir.

Then, the barrier metal film can be prevented from substantially losing its conductivity due to the oxidation thereof as intended.

In order to achieve the first object, a first process for fabricating a semiconductor device according to the present invention includes the steps of: forming a recess in an insulating film on a substrate; sequentially depositing a barrier metal film of a metal whose conductivity will not be lost when the metal is oxidized or of a conductive metal oxide and a first conductive film of copper or a copper alloy on wall surfaces of the recess; growing a second conductive film of copper or a copper alloy on the first conductive film by an electroplating process so as to completely fill the recess; and integrating the first and second conductive films into a third conductive film so as to form an embedded wiring of the third conductive film.

According to the first fabrication method, the barrier metal film of a metal whose conductivity will not be lost when the metal is oxidized or of a conductive metal oxide and the first conductive film are sequentially deposited on wall surfaces of the recess formed in the insulating film on the substrate. Thereafter, the second conductive film is grown on the first conductive film by the electroplating process so as to completely fill the recess. Then, the first and second conductive films are integrated into the third conductive

film so as to form the embedded wiring of the third conductive film. Suppose that the barrier metal film and the first conductive film, i.e., the seed layer are sequentially deposited on wall surfaces of the recess. In that case, even when the barrier metal has exposed parts due to poor coverage of the seed layer, it can be avoided that the conductivity of the exposed parts of the barrier metal film will be substantially lost due to the oxidation of its exposed parts. This enables the formation of a second conductive film on the seed layer or the barrier metal film in the recess by the electroplating process, while preventing generation of filling defects.

In order to achieve the second object, a second process for fabricating a semiconductor device according to the present invention includes the steps of: sequentially depositing a barrier metal film of a metal whose conductivity will not be lost when the metal is oxidized or of a conductive metal oxide and a first conductive film of copper or a copper alloy on an insulating film overlying a substrate; growing a second conductive film of copper or a copper alloy on the first conductive film by an electroplating process; integrating the first and second conductive films into a third conductive film; and forming a wiring of the third conductive film by etching the third conductive film using a mask pattern covering a wiring

forming region.

According to the second fabrication method, the barrier metal film of a metal whose conductivity will not be lost when the metal is oxidized or of a conductive metal oxide and the first conductive film are sequentially deposited. Thereafter, the second conductive film is grown on the first conductive film by the electroplating process. Then, the first and second conductive films are integrated into the third conductive film. The third conductive film is etched so as to form the wiring. Suppose that the barrier metal film and the first conductive film, i.e., the seed layer are sequentially deposited on the insulating film. In that case, even when the barrier metal film has exposed parts due to poor coverage of the seed layer, it can be avoided that the conductivity of the exposed parts of the barrier metal film will be substantially lost due to the oxidation of its exposed parts. Thus, wiring resistance can be prevented from increasing due to the oxidation of the barrier metal film.

In order to achieve the second object, a third process for fabricating a semiconductor device according to the present invention includes the steps of: forming a recess in an insulating film on a substrate; depositing a barrier metal film of a metal whose conductivity will not be lost when the metal is oxidized or of a conductive metal oxide on wall surfaces of the recess; and forming a conductive film of

copper or a copper alloy on the barrier metal film to completely fill the recess and thereby forming an embedded wiring of the conductive film.

According to the third fabrication method, the barrier metal film of a metal whose conductivity will not be lost when the metal is oxidized or of a conductive metal oxide is deposited on wall surfaces of the recess formed in the insulating film on the substrate. Thereafter, the conductive film is formed on the barrier metal film so as to completely fill the recess. In this manner, the embedded wiring of the conductive film is formed. Thus, when the barrier metal film is deposited on wall surfaces of the recess and then the conductive film is formed on the barrier metal film, e.g., in an oxidative atmosphere, it can be avoided that the conductivity of the barrier metal film will be substantially lost due to the oxidation thereof. Thus, wiring resistance can be prevented from increasing due to the oxidation of the barrier metal film.

In order to achieve the second object, a fourth process for fabricating a semiconductor device according to the present invention includes the steps of: depositing a barrier metal film of a metal whose conductivity will not be lost when the metal is oxidized or of a conductive metal oxide on an insulating film overlying a substrate; forming a conductive film of copper or a copper alloy on the barrier

metal film; and forming a wiring of the conductive film by etching the conductive film using a mask pattern covering a wiring forming region.

In the fourth fabrication method, the barrier metal film of a metal whose conductivity will not be lost when the metal is oxidized or of a conductive metal is deposited on the insulating film overlying the substrate. Thereafter, the conductive film is formed on the barrier metal film. Then, the wiring of the conductive film is formed by etching the conductive film. Thus, when the barrier metal film is deposited on the insulating film and then the conductive film is formed on the barrier metal film, e.g., in an oxidative atmosphere, it can be avoided that the conductivity of the barrier metal film will be substantially lost due to the oxidation thereof. Thus, wiring resistance can be prevented from increasing due to the oxidation of the barrier metal film.

In the third and/or fourth fabrication methods, the conductive film is preferably deposited by a sputtering process and then caused to flow in an oxidative-reducing atmosphere.

Then, the coverage of the conductive film is improved.

In the first, second, third and/or fourth fabrication methods, the metal is preferably Ru, Ir or an alloy containing Ru or Ir.

Then, the the barrier metal film can be prevented from substantially losing its conductivity due to the oxidation thereof as intended.

In the first, second, third and/or fourth fabrication methods, the metal oxide is preferably RuO_2, IrO_2 or an alloy oxide containing Ru or Ir.

Then, the the barrier metal film can be prevented from substantially losing its conductivity due to the oxidation thereof as intended..

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1A** through **1E** are cross-sectional views illustrating respective steps of a method for fabricating a semiconductor device according to a first embodiment of the present invention.

FIGS. **2A** through **2E** are cross-sectional views illustrating respective steps of a method for fabricating a semiconductor device according to a second embodiment of the present invention.

FIGS. **3A** through **3D** are cross-sectional views illustrating respective steps of a method for fabricating a semiconductor device according to a third embodiment of the present invention.

FIGS. **4A** through **4E** are cross-sectional views illustrating some steps of a method for fabricating a

semiconductor device according to a fourth embodiment of the present invention.

FIGS. **5A** through **5D** are cross-sectional views illustrating other steps of the method for fabricating a semiconductor device according to the fourth embodiment of the present invention.

FIGS. **6A** through **6E** are cross-sectional views illustrating respective steps of a conventional method for fabricating a semiconductor device.

FIGS. **7A** through **7B** are cross-sectional views for describing problems of the conventional method for fabricating a semiconductor device.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

EMBODIMENT 1

Hereinafter, a semiconductor device and a fabrication method thereof according to the first embodiment of the present invention will be described with reference to FIGS. **1A** through **1E**.

First, as shown in FIG. **1A**, a first wiring **103** of, e.g., a copper film is embedded in a first insulating film **101** on a semiconductor substrate **100** with a first barrier metal film **102** of, e.g., a Ta film interposed therebetween. Then, a first silicon nitride film **104**, a second insulating film **105**, a second silicon nitride film **106** and a third insulating film

107 are sequentially deposited on the semiconductor substrate 100. A via hole 108 reaching the first wiring 103 is then formed through the first silicon nitride film 104, second insulating film 105 and second silicon nitride film 106. The via hole 108 has a depth of about 500 nm. A wiring trench 109 reaching the first wiring 103 through the via hole 108 is also formed in the third insulating film 107. The wiring trench 109 has a depth of about 300 nm. The first barrier metal film 102 or the first silicon nitride film 104 prevents copper atoms of the first wiring 103 from diffusing into the first insulating film 101, the second insulating film 105 or the like due to the thermal processing at about 400°C (e.g., plasma CVD process) for depositing the second insulating film 105, the second silicon nitride film 106 or the like. In other words, the first barrier metal film 102 or the first silicon nitride film 104 serves as a barrier against diffusion of the copper atoms.

Next, as shown in FIG. 1B, a second barrier metal film 110 of a Ru (ruthenium) film is then deposited to a thickness of 25 nm on the semiconductor substrate 100 by, e.g., a sputtering process. Thereafter, a copper seed layer 111 of a copper film is deposited to a thickness of 150 nm on the second barrier metal film 110 by, e.g., a sputtering process. Thus, the bottoms and wall surfaces of each of the via hole 108 and the wiring trench 109 are covered with the second

barrier metal film **110** and the copper seed layer **111**.

The semiconductor substrate **100** is then transferred from the sputtering apparatus into a plating apparatus. At this time, if the second barrier metal film **110** has exposed parts due to the poor coverage of the copper seed layer **111**, those parts will be exposed to the air and therefore oxidized. However, in this embodiment, the specific resistance of Ru of which the second barrier metal film **110** is made is 7.5 $\mu\Omega \cdot$ cm, while the specific resistance of RuO_2, which is a Ru oxide, is 35 $\mu\Omega \cdot$ cm. Therefore, even when the second barrier metal film **110** is oxidized, the conductivity thereof will not be lost.

Then, as shown in FIG. **1C**, a copper plating film **112** is grown to a thickness of 500 nm on the copper seed layer **111** by an electroplating process so as to completely fill the via hole **108** and the wiring trench **109**. More specifically, with the semiconductor substrate **100** being immersed in a plating solution including $CuSO_4$, H_2SO_4 and the like, the electroplating process is conducted such that the semiconductor substrate **100** has a negative potential. At this time, even if those parts of the second barrier metal film **110** which are located on the wall surfaces of the via hole **108** or the like are not covered with the copper seed layer **111**, it can be avoided that the conductivity of the second barrier metal film **110** will be substantially lost due

to oxidation thereof. Thus, the via hole **108** and the wiring trench **109** can be reliably filled with the copper plating film **112**.

Thereafter, the semiconductor substrate **100** is removed from the plating apparatus, and then the copper plating film **112** is thermally processed (e.g., at about 100℃ for about two hours) in order to grow crystal grains of the copper plating film **112**. As a result, the copper seed layer **111** and the copper plating film **112** are integrated into a wiring copper film **113** as shown in FIG. **1D**. Note that, instead of thermally processing the copper plating film **112**, the semiconductor substrate **100** may be left to stand at room temperature for about two days.

As shown in FIG. **1E**, by for example a CMP (chemical mechanical polishing) process, those parts of the second barrier metal film **110** and the wiring copper film **113** which are located outside the wiring trench **109** are then removed to form a via **114** and a second wiring **115** from the wiring copper film **113**. Thus, the first wiring **103** is connected to the second wiring **115** through the via **114**.

Although not shown in the figure, a desired multi-layer wiring structure is then formed as necessary by repeatedly conducting the steps of FIGS. **1A** through **1E** (regarding FIG. **1A**, the step of depositing the first silicon nitride film **104** and the subsequent steps).

As has been described above, according to the first embodiment, the second barrier metal film **110** of Ru, i.e., a "metal whose conductivity will not be lost when the metal oxidized" and the copper seed layer **111** are sequentially deposited on the bottoms and wall surfaces of each of the via hole **108** and the wiring trench **109**. Thereafter, by an electroplating process, the copper plating film **112** is grown on the copper seed layer **111** so as to completely fill the via hole **108** and the wiring trench **109**. Then, the copper seed layer **111** and the copper plating film **112** are integrated into the wiring copper film **113**, so that the via **114** and the second wiring **115** are formed from the wiring copper film **113**. Suppose that the second barrier metal film **110** and the copper seed layer **111** are sequentially deposited on the wall surfaces of the via hole **108** or the wiring trench **109**. In that case, even when the second barrier metal film **110** has exposed parts due to poor coverage of the copper seed layer **111**, it can be avoided that the conductivity of the exposed parts of the copper seed layer **111** will be substantially lost. This enables the formation of the copper plating film **112** on the copper seed layer **111** and the second barrier metal film **110** in the via hole **108** or the wiring trench **109** by an electroplating process, while preventing generation of filling defects. As a result, a margin of filling the via hole **108** or the wiring trench **109** with the copper plating

film **112** is increased.

In the first embodiment, Ru is used as a material of the second barrier metal film **110**. However, any "metal whose conductivity will not be lost when the metal is oxidized", e.g., Ir (specific resistance 6.5 $\mu\Omega \cdot$ cm: the specific resistance of IrO_2, which is an Ir oxide, is about 30 $\mu\Omega \cdot$ cm), an alloy containing Ru or Ir may alternatively be used.

In the first embodiment, pure copper is used as a material of the first wiring **103**, the copper seed layer **111** or the copper plating film **112**. However, a copper alloy may alternatively be used.

In the first embodiment, a Ta film is used as the first barrier metal film **102**. However, a TaN film, a Ti film, a TiN film or the like may alternatively be used.

In the first embodiment, an SiO_2 film, an SOG (Spin On Glass) film, a film which is deposited by using a CVD process, includes C and has a low dielectric constant, or the like may be used as the first insulating film **101**, second insulating film **105** or third insulating film **107**.

A dual damascene process in which the via hole **108** and the wiring trench **109** are simultaneously filled with a conductive film is used in the first embodiment. Alternatively, the via hole **108** and the wiring trench **109** may be separately formed and then separately filled with a conductive film.

In the first embodiment, in order to reduce the resistance of the first wiring **103** as well as the first barrier metal film **102** of a Ta film, some metal film other than a Ta film may be formed under the first barrier metal film **102**.

In the first embodiment, in order to reduce the resistance of the via **114** or the second wiring **115** as well as the second barrier metal film **110** of a Ru film, some metal film other than a Ru film may be formed under the second barrier metal film **110**.

EMBODIMENT 2

Hereinafter, a semiconductor device and a fabrication method thereof according to the second embodiment of the present invention will be described with reference to FIGS. **2A** through **2E**.

First, like the step of FIG. **1A** in the first embodiment, as shown in FIG. **2A**, a first wiring **203** of, e.g., a copper film is embedded in a first insulating film **201** on a semiconductor substrate **200** with a first barrier metal film **202** of, e.g., a Ta film interposed therebetween. Then, a first silicon nitride film **204**, a second insulating film **205**, a second silicon nitride film **206** and a third insulating film **207** are sequentially deposited on the semiconductor substrate **200**. A via hole **208** reaching the first wiring **203** is then

formed through the first silicon nitride film **204**, second insulating film **205** and second silicon nitride film **206**. The via hole **208** has a depth of about 500 nm. A wiring trench **209** reaching the first wiring **203** through the via hole **208** is also formed in the third insulating film **207**. The wiring trench **209** has a depth of about 300 nm. The first barrier metal film **202** or the first silicon nitride film **204** prevents copper atoms of the first wiring **203** from diffusing into the first insulating film **201**, the second insulating film **205** or the like due to the thermal processing at about 400°C (e.g., plasma CVD process) for depositing the second insulating film **205**, the second silicon nitride film **206** or the like. In other words, the first barrier metal film **202** or the first silicon nitride film **204** serves as a barrier against diffusion of the copper atoms.

Next, as shown in FIG. **2B**, a second barrier metal film **210** of RuO_2 is deposited to a thickness of 25 nm on the semiconductor substrate **200** by, e.g., a reactive sputtering process in which sputtering is carried out using Ru as sputtering targets in an atmosphere of oxygen (O_2). Thereafter, a copper seed layer **211** of copper is deposited to a thickness of 150 nm on the second barrier metal film **210** by, e.g., a sputtering process. Thus, the bottoms and wall surfaces of each of the via hole **208** and the wiring trench **209** are covered with the second barrier metal **210** and the

copper seed layer **211**.

The semiconductor substrate **200** is then transferred from the sputtering apparatus into a plating apparatus. At this time, if the second barrier metal film **210** has exposed parts due to poor coverage of the copper seed layer **211**, those parts will be exposed to the air. However, RuO_2 (specific resistance of 35 $\mu\Omega \cdot$ cm) itself, of which the second barrier metal **210** is made, is a conductive metal oxide and thus will never cause further oxidation to substantially lose its conductivity.

Then, as shown in FIG. **2C**, a copper plating film **212** is grown to a thickness of 500 nm on the copper seed layer **211** by an electroplating process so as to completely fill the via hole **208** and the wiring trench **209**. More specifically, with the semiconductor substrate **200** being immersed in a plating solution including $CuSO_4$, H_2SO_4 and the like, the electroplating process is conducted such that the semiconductor substrate **200** has a negative potential. At this time, even if the second barrier metal film **210** on wall surfaces of the via hole **208** or the like is not covered with the copper seed layer **211**, it can be avoided the conductivity of the second barrier metal film **210** will be substantially lost due to oxidation thereof. Thus, the via hole **208** and the wiring trench **209** can be reliably filled with the copper plating film **212**.

Thereafter, the semiconductor substrate **200** is removed from the plating apparatus, and the copper plating film **212** is thermally processed (e.g., at about 100℃ for about two hours) in order to grow crystal grains of the copper plating film **212**. As a result, the copper seed layer **211** and the copper plating film **212** are integrated into a wiring copper film **213** as shown in FIG. **2D**. Note that, instead of thermally processing the copper plating film **212**, the semiconductor substrate **200** may be left to stand at room temperature for about two days.

As shown in FIG. **2E**, by, e.g., a CMP process, those parts of the second barrier metal film **210** and the wiring copper film **213** which are located outside the wiring trench **209** are then removed to form a via **214** and a second wiring **215** from the wiring copper film **213**. Thus, the first wiring **203** is connected to the second wiring **215** through the via **214**.

Although not shown in the figure, a desired multi-layer wiring structure is then formed as necessary by repeatedly conducting the steps of FIGS. **2A** through **2E** (regarding FIG. **2A**, the step of depositing the first silicon nitride film **204** and the subsequent steps).

As has been described above, according to the second embodiment, the second barrier metal film **210** of RuO_2, i.e., a "conductive metal oxide" and the copper seed layer **211** are sequentially deposited on the bottoms and wall surfaces of

each of the via hole **208** and the wiring trench **209**. Thereafter, by an electroplating process, the copper plating film **212** is grown on the copper seed layer **211** so as to completely fill the via hole **208** and the wiring trench **209**. Then, the copper seed layer **211** and the copper plating film **212** are integrated into the wiring copper film **213**, so that the via **214** and the second wiring **215** are formed from the wiring copper film **213**. Suppose that the second barrier metal film **210** and the copper seed layer **211** are sequentially deposited on the wall surface of the via hole **208** or wiring trench **209**. In that case, even when the second barrier metal film **210** has exposed parts due to poor coverage of the copper seed layer **211**, it can be avoided that the conductivity of the exposed parts will be substantially lost due to the oxidation thereof. This enables the formation of the copper plating film **212** on the copper seed layer **211** and the second barrier metal film **210** in the via hole **208** or the wiring trench **209** by an electroplating process, while preventing generation of filling defects. As a result, a margin of filling the via hole **208** or the wiring trench **209** with the copper plating film **212** is increased.

In the second embodiment, RuO_2 is used as a material of the second barrier metal film **210**. However, any "conductive metal oxide", e.g., IrO_2 (specific resistance of 30 $\mu\Omega \cdot$ cm), an alloy oxide containing Ru or Ir, a superconducting oxide

such as YBCO ($YBa_2Cu_3O_{7-x}$), or a compound such as $La_{0.8}Sr_{0.2}MnO_3$ may alternatively be used.

In the second embodiment, pure copper is used as a material of the first wiring **203**, the copper seed layer **211** or the copper plating film **212**. However, a copper alloy may alternatively be used.

In the second embodiment, a Ta film is used as the first barrier metal film **202**. However, a TaN film, a Ti film, a TiN film or the like may alternatively be used.

In the second embodiment, an SiO_2 film, an SOG film, a CVD film including C and having a low dielectric constant, or the like may be used as the first insulating film **201**, second insulating film **205** or third insulating film **207**.

A dual damascene process in which the via hole **208** and the wiring trench **209** are simultaneously filled with a conductive film is used in the second embodiment. Alternatively, the via hole **208** and the wiring trench **209** may be separately formed and separately filled with a conductive film.

In the second embodiment, in order to reduce the resistance of the first wiring **203** as well as the first barrier metal film **202** of a Ta film, some metal film other than a Ta film may be formed under the first barrier metal film **202**.

In the second embodiment, in order to reduce the

resistance of the via **214** or the second wiring **215** as well as the second barrier metal film **210** of a RuO_2 film, some metal film other than a RuO_2 film under the second barrier metal film **210**.

EMBODIMENT 3

Hereinafter, a semiconductor device and a fabrication method thereof according to the third embodiment of the present invention will be described with reference to FIGS. **3A** through **3D**.

First, like the step of FIG. **1A** in the first embodiment, as shown in FIG. **3A**, a first wiring **303** of, e.g., a copper film is embedded in a first insulating film **301** on a semiconductor substrate **300** with a first barrier metal film **302** of, e.g., a Ta film interposed therebetween. Then, a first silicon nitride film **304**, a second insulating film **305**, a second silicon nitride film **306** and a third insulating film **307** are sequentially deposited on the semiconductor substrate **300**. A via hole **308** reaching the first wiring **303** is then formed through the first silicon nitride film **304**, second insulating film **305** and second silicon nitride film **306**. The via hole **308** has a depth of about 500 nm. A wiring trench **309** reaching the first wiring **303** through the via hole **308** is also formed in the third insulating film **307**. The wiring trench **309** has a depth of about 300 nm. The first barrier

metal film **302** or the first silicon nitride film **304** prevents copper atoms of the first wiring **303** from diffusing into the first insulating film **301**, the second insulating film **305** or the like due to the thermal processing at about 400℃ (e.g., plasma CVD process) for depositing the second insulating film **305**, the second silicon nitride film **306** or the like. In other words, the first barrier metal film **302** or the first silicon nitride film **304** serves as a barrier against diffusion of the copper atoms.

As shown in FIG. **3B**, a second barrier metal film **310** of, e.g., a Ru film is then deposited on the semiconductor substrate **300** to a thickness of 25 nm by, e.g., a sputtering process. Accordingly, the bottoms and wall surfaces of each of the via hole **308** and the wiring trench **309** are covered with the second barrier metal film **310**. Thereafter, a wiring copper film **311** is deposited to a thickness of 600 nm on the second barrier metal film **310** by, e.g., a sputtering process. At this time, the via hole **308** or the wiring trench **309** cannot completely be filled with the wiring copper film **311** due to the directivity of the sputtering process, as shown in FIG. **3B**.

As shown in FIG. **3C**, the wiring copper film **311** is then repeatedly oxidized and reduced in an oxidative-reducing atmosphere by, e.g., an oxidation-reduction reflow process. The resultant reaction heat causes the wiring copper film **311**

to flow, thereby completely filling the via hole **308** or the wiring trench **309**. Note that, upon oxidizing the wiring copper film **311**, the second barrier metal **310** is also oxidized simultaneously. However, the specific resistance of Ru of which the second barrier metal film **310** is made is 7.5 $\mu\Omega \cdot$ cm, while the specific resistance of an Ru oxide, RuO_2 is 35 $\mu\Omega \cdot$ cm. Therefore, the second barrier metal film **310** will not lose its conductivity when oxidized.

As shown in FIG. **3D**, by, e.g., a CMP process, those parts of the second barrier metal film **310** and the wiring copper film **311** which are located outside the wiring trench **309** are then removed to form a via **312** and a second wiring **313** from the wiring copper film **311**. Thus, the first wiring **303** is connected to the second wiring **313** through the via **312**.

Although not shown in the figure, a desired multi-layer wiring structure is then formed as necessary by repeatedly conducting the steps of FIGS. **3A** through **3D** (regarding FIG. **3A**, the step of depositing the first silicon nitride film **304** and the subsequent steps).

As has been described above, according to the third embodiment, the second barrier metal film **310** of Ru, i.e., a "metal whose conductivity will not be lost when the metal is oxidized" is deposited on the bottoms and wall surfaces of each of the via hole **308** and the wiring trench **309**. Thereafter, the wiring copper film **311** is formed on the

second barrier metal film **310** so as to completely fill the via hole **308** and the wiring trench **309**. In this manner, the via **312** and the second wiring **313** are formed. Accordingly, even when the second barrier metal film **310** is deposited on the wall surfaces of the via hole **308** or the wiring trench **309** and then the wiring copper film **311** is formed on the second barrier metal film **310**, e.g., in an oxidative atmosphere, it can be avoided that the conductivity of the second barrier metal film **310** will not be lost due to the oxidation thereof. Thus, the resistance of the via **312** or the second wiring **313** as well as the second barrier metal film **310** can be prevented from increasing due to the oxidation of the second barrier metal film **310**.

In the third embodiment, Ru is used as a material of the second barrier metal film **310**. However, any "metal whose conductivity will not be lost when the metal is oxidized", e.g., Ir or an alloy containing Ru or Ir may alternatively be used. Also, instead of a "metal whose conductivity will not be lost when the metal is oxidized", a "conductive metal oxide", e.g., RuO_2, IrO_2, an alloy oxide containing Ru or Ir, a superconducting oxide such as YBCO, or a compound such as $La_{0.9}Sr_{0.2}MnO_3$ may alternatively be used.

In the third embodiment, pure copper is used as a material of the first wiring **303** or the copper seed layer **311**. However, a copper alloy may alternatively be used.

In the third embodiment, a Ta film is used as the first barrier metal film **302**. However, a TaN film, a Ti film, a TiN film or the like may alternatively be used.

In the third embodiment, an SiO_2 film, an SOG film, a CVD film including C and having a low dielectric constant, or the like may be used as the first insulating film **301**, second insulating film **305** or third insulating film **307**.

In the third embodiment, in order to form the wiring copper film **311**, a combination of sputtering and reflow processes is used. However, a CVD process, an electroless plating process, an ion plating process, a combination of CVD and high-temperature sputtering processes (a process in which after a thin copper film has been deposited by a CVD process, a thick copper film is deposited on the thin film by a high-temperature sputtering process) or the like may alternatively used. Also, in this embodiment, an oxidative-reducing reflow process is used as the reflow process in the combination of sputtering and reflow processes. However, some other reflow process may alternatively be used.

A dual damascene process in which the via hole **308** and the wiring trench **309** are simultaneously filled with a conductive film is used in the third embodiment. Alternatively, the via hole **308** and the wiring trench **309** may be separately formed and separately filled with a conductive film.

In the third embodiment, in order to reduce the resistance of the first wiring **303** as well as the first barrier metal film **302** of a Ta film, some metal film other than a Ta film may be formed under the first barrier metal film **302**.

In the third embodiment, in order to reduce the resistance of the via **312** or the second wiring **313** as well as the second barrier metal film **310** of a Ru film, some metal film other than a Ru film under the second barrier metal film **310**.

EMBODIMENT 4

Hereinafter, a semiconductor device and a fabrication method thereof according to the fourth embodiment of the present invention will be described with reference to FIGS. **4A** through **4E** and FIGS. **5A** through **5D**.

First, as shown in FIG. **4A**, a first barrier metal film **402** of a Ru film is deposited on a first insulating film **401** overlying a semiconductor substrate **400** to a thickness of 10 nm by, e.g., a sputtering process. Thereafter, a copper seed layer **403** of a copper film is deposited to a thickness of 100 nm on the first barrier metal film **402** by, e.g., a sputtering process.

The semiconductor substrate **400** is then transferred from the sputtering apparatus into a plating apparatus. At this

time, if the first barrier metal film **402** has exposed parts due to the poor coverage of the copper seed layer **403**, those parts will be exposed to the air and therefore oxidized. However, in this embodiment, the specific resistance of Ru of which the first barrier metal film **402** is made is 7.5 $\mu\Omega \cdot$ cm, while the specific resistance of RuO_2, which is a Ru oxide, is 35 $\mu\Omega \cdot$ cm. Thus, even when the first barrier metal film **402** is oxidized, the conductivity thereof will not be lost.

Then, as shown in FIG. **4A**, a copper plating film **404** is grown to a thickness of 500 nm on the copper seed layer **403** by an electroplating process. More specifically, with the semiconductor substrate **400** being immersed in a plating solution including $CuSO_4$, H_2SO_4 and the like, the electroplating process is conducted such that the semiconductor substrate **400** has a negative potential. Note that, although not shown in the figure, in the case where the first insulating film **401** has a recess such as a contact hole or via hole, the recess is filled with the copper plating film **404** with the first barrier metal film **402** and the copper seed layer **403** interposed therebetween.

Thereafter, the semiconductor substrate **400** is removed from the plating apparatus, and the copper plating film **404** is thermally processed (e.g., at about 100℃ for about two hours) in order to grow crystal grains of the copper plating

film **404**. As a result, the copper seed layer **403** and the copper plating film **404** are integrated into a first wiring copper film **405**, as shown in FIG. **4B**. Note that, instead of thermally processing the copper plating film **404**, the semiconductor substrate **400** may be left to stand at room temperature for about two days.

As shown in FIG. **4B**, a first resist pattern **406** is then formed on the first wiring copper film **405** so as to cover a first wiring forming region.

Next, by using the first resist pattern **406** as a mask, the first wiring copper film **405** and the first barrier metal film **402** are sequentially etched to form a first wiring **407** on the first insulating film **401** with the first barrier metal film **402** interposed therebetween, as shown in FIG. **4C**.

Thereafter, as shown in FIG. **4D**, a silicon nitride film **408** and a second insulating film **409** are sequentially deposited on the first wiring **407** and the first insulating film **401**. As a result, the top and side surfaces of the first wiring **407** are covered with the second insulating film **409** with the silicon nitride film **408** interposed therebetween. The first barrier metal film **402** or the silicon nitride film **408** prevents copper atoms of the first wiring **407** from diffusing into the first insulating film **401**, the second insulating film **409** or the like due to the thermal processing at about 400℃ (e.g., plasma CVD process) for depositing the

second insulating film **409** or the like. In other words, the first barrier metal film **402** or the silicon nitride film **408** serves as a barrier against diffusion of the copper atoms.

As shown in FIG. **4E**, a via hole **410** reaching the first wiring **407** is then formed through the silicon nitride film **408** and the second insulating film **409**. The via hole **410** has a depth of about 500 nm.

As shown in FIG. **5A**, a second barrier metal film **411** of a Ru film is then deposited to a thickness of 25 nm on the second insulating film **409** as well as in the via hole **410** by, e.g., a sputtering process. Thus, the bottom and wall surface of the via hole **410** are covered with the second barrier metal film **411**.

Thereafter, a second wiring copper film **412** is deposited to a thickness of 600 nm on the second barrier metal film **411** by, e.g., a sputtering process. At this time, the via hole **410** cannot completely be filled with the second wiring copper film **412** due to the directivity of the sputtering process, as shown in FIG. **5A**.

As shown in FIG. **5B**, the second wiring copper film **412** is then repeatedly oxidized and reduced in an oxidative-reducing atmosphere by, e.g., an oxidation-reduction reflow process. The resultant reaction heat causes the second wiring copper film **412** to flow, thereby completely filling the via hole **410**. Note that, upon oxidizing the second

wiring copper film **412**, the second barrier metal film **411** is also oxidized simultaneously. However, the specific resistance of Ru of which the second barrier metal film **411** is made is 7.5 $\mu\Omega \cdot$ cm, while the specific resistance of RuO_2, which is a Ru oxide, is 35 $\mu\Omega \cdot$ cm. Thus, even when the second barrier metal film **411** is oxidized, the conductivity thereof will not be lost.

As shown in FIG. **5C**, a second resist pattern **413** is then formed on the second wiring copper film **412** so as to cover a second wiring forming region. By using the second resist pattern **413** as a mask, the second wiring copper film **412** and the second barrier metal film **411** are sequentially etched to form a via **414** and a second wiring **415** from the second wiring copper film **412**, as shown in FIG. **5D**. Thus, the first wiring **407** is connected to the second wiring **415** through the via **414**.

Although not shown in the figure, a desired multi-layer wiring structure is then formed as necessary by repeatedly conducting the steps of FIGS. **4D** and **4E** and FIGS. **5A** through **5D**.

As has been described above, according to the fourth embodiment, the first barrier metal film **402** of Ru, i.e., a "metal whose conductivity will not be lsot when the metal is oxidized," and the copper seed layer **403** are sequentially deposited on the first insulating film **401**. Thereafter, by an electroplating process, the copper plating film **404** is

grown on the copper seed layer **403**. Then, the copper seed layer **403** and the copper plating film **404** are integrated into the first wiring copper film **405**. The first wiring copper film **405** is etched to form the first wiring **407**. Suppose that the first barrier metal film **402** and the copper seed layer **403** are sequentially deposited on the first insulating film **401**. In that case, even when the first barrier metal film **402** has exposed parts due to poor coverage of the copper seed layer **403**, it can be avoided that the conductivity of the exposed parts will be substantially lost due to the oxidation thereof. Therefore, the resistance of the first wiring **407** as well as the first barrier metal film **402** can be prevented from increasing due to the oxidation of the first barrier metal film **402**.

In the fourth embodiment, the second barrier metal film **411** of Ru, i.e., a "metal whose conductivity will not be lost when the metal is oxidized," is deposited on the second insulating film **409** as well as in the via hole **410**. Thereafter, the second wiring copper film **412** is formed on the second barrier metal **411** so as to completely fill the via hole **410**. Then, the second wiring copper film **412** is etched to form the via **414** and the second wiring **415**. Thus, even when the second barrier metal film **411** is deposited on the second insulating film **409** and then the second wiring copper film **412** is formed on the second barrier metal film **411**, e.g.,

in an oxidative atmosphere, it can be avoided that the conductivity of the second barrier metal film **411** will be substantially lost due to the oxidation thereof. Therefore, the resistance of the via **414** or the second wiring **415** as well as the second barrier metal film **411** can be prevented from increasing due to the oxidation of the second barrier metal film **411**.

In the fourth embodiment, Ru is used as a material of the first barrier metal film **402** or the second barrier metal film **411**. However, any "metal whose conductivity will not be lost when the metal is oxidized", e.g., Ir or an alloy containing Ru or Ir may alternatively be used. Also, instead of a "metal whose conductivity will not be lost when the metal is oxidized", a "conductive metal oxide", e.g., RuO_2, IrO_2, an alloy oxide containing Ru or Ir, a superconducting oxide such as YBCO, or a compound such as $La_{0.8}Sr_{0.2}MnO_3$ may alternatively be used.

In the fourth embodiment, pure copper is used as a material of the copper seed layer **403**, the copper plating film **404** or the second wiring copper film **412**. However, a copper alloy may alternatively be used.

In the fourth embodiment, an SiO_2 film, an SOG film, a CVD film including C and having a low dielectric constant, or the like may be used as the first insulating film **401** or second insulating film **409**.

In the fourth embodiment, in order to form the second wiring copper film **412**, the combination of sputtering and reflow processes is used. However, a CVD process, an electroless plating process, an ion plating process, a combination of CVD and high temperature sputtering processes or the like may alternatively used. Also, in this embodiment, an oxidative-reducing reflow process is used as the reflow process in the combination of sputtering and reflow processes. However, some other reflow process may alternatively be used.

In the fourth embodiment, in order to reduce the resistance of the first wiring **407** as well as the first barrier metal film **402** of a Ru film, some metal film other than a Ru film may be formed under the first barrier metal film **402**.

In the fourth embodiment, in order to reduce the resistance of the via **414** or the second wiring **415** as well as the second barrier metal film **411** of a Ru film, some metal film other than a Ru film under the second barrier metal film **411**.